DOCUMENT RESUME

ED 382 472 SE 056 277

AUTHOR Chiu, Mei-Hung
TITLE Self-Explanations Promotes Science Learning.
PUB DATE Apr 95
NOTE 24p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (San Francisco, CA, April 22-25, 1995).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Chemical Equilibrium; *Chemistry; Foreign Countries; High Schools; *High School Students; Interviews; Science Education; *Scientific Concepts
IDENTIFIERS *Explanations; *Science Achievement

ABSTRACT

The use of the method of self-explanations to gain knowledge on students' conception of the chemical equilibrium concepts is reported in this paper. The analysis provides information on: (1) a general indication of students' understanding of materials related to chemical equilibrium, (2) a deep investigation of problem solving skills associated with the content, (3) a close look on inferences generated during studying the materials, and (4) a comparison of successful, intermediate, and unsuccessful students' performances which were resulted from the pre- and post-treatments. The findings obtained were based on verbal protocols of (n=12) high school students before, during, and after the experiment. Results indicated that high quality of self-explanations promote better understanding of the chemical concepts and principles. (Author)

Paper presented at the annual meeting for the National Association for Research in Science Teaching (NARST), San Francisco, CA, USA, April 22-25, 1995.

Self-Explanations Promotes Science Learning

Mei-Hung Chiu

National Taiwan Normal University
Graduate Institute of Science Education

ABSTRACT

The use of the method of self-explanations to gain knowledge on the students' conception of the chemical equilibrium concepts is reported. The analysis provides information on : (a) A general indication of students' understanding of materials related to chemical equilibrium. (b) A deep investigation of problem solving skills associated with the content. (c) A close look on inferences generated during studying the materials. (d) A comparison of successful, intermediate, unsuccessful students' performances which were resulted from the pre- and post-treatments. The findings obtained were based on verbal protocols of twelve high school students before, during, and after the experiment. Results indicated that high quality of self-explanations promote better understanding of the chemical concepts and principles.

Introduction

Research has shown that students prefer to rely on worked-out examples in a text rather than the prose parts of the text (LeFevre & Dixon, 1986; Zhu & Simon, 1987). Also, Chi, et al.'s study (1989) indicate that students learn maximally from worked-out examples when they provide their own explanations for the actions in the examples. Chi and her colleagues further suggest that some characteristics of self-explaining are considered as reasons for the gains in deeper understanding (Chi, deLeeuw, Chiu, and Lavancher, 1994).

The overarching question guiding this research was an attempt to understand why it is difficult to learn some chemical concepts, whether students perform differently during problem solving processes, and how students promote their understanding of concepts and principles via self-explanations.

I use the quote below from Resnick (1989) to indicate the need of self-constructive activity for meaningful learning.

> *Learning is a process of knowledge construction, not of knowledge recording or absorption. Learning is also knowledge-dependent; people use current knowledge to construct new knowledge.*

Objectives and theoretical framework

Chi and her colleagues (1994) proposed an active knowledge construction strategy, self-explaining. The active construction of new knowledge necessarily means that more highly connected and coherent knowledge structures are being built. Anderson (1990, p.181-2) has also conjectured that elaborations can lead to better memory in at least two ways. First, they provide redundant retrieval routes for recall. Because the elaborated structure would help recall by providing the subject with alternate retrieval routes through the network to be used should the more direct ones fail. Second, elaboration aids memory is that it helps individuals to infer what they can no longer actually remember. Briefly speaking, elaborations increase the redundancy with which information is encoded in memory.

In chemistry, various methods have been used to elucidate the structure of domain knowledge about chemical equilibrium (Gorodetsky & Gussarsky, 1986; Gorodetsky & Hoz, 1985; Gabel, Sherwood, & Enochs, 1984), but there has been little on successful and unsuccessful problem-solving performance by novice and experts on chemical equilibrium problems (eg., Camacho and Good, 1989). Furthermore, students' conceptual core of specific knowledge about chemical equilibrium has not been carefully examined either.

As part of a larger project aimed at examining how students generate explanations and change concepts resulting from studying assigned readings associated with chemical equilibrium, I focus in this report on how twelve high school students came to understand the concepts and principles via self-explanations. Based upon the theoretical hypothesis and empirical findings, I posit reasons why the contents of self-explanations were crucial in helping students integrate scientific knowledge and solve problems. From this analysis, I intend to identify with some confidence about the students' problem solving skills and characteristics of inferences in learning of chemical equilibrium.

Method

Participants. Twelve high school students from a local high school in . Taipei, Taiwan, voluntarily participated in this research. They were individually interviewed by the researcher using the think-aloud method. With this method students were given tasks and asked to describe how they learned the materials and how they were solving the task. All the interviews were audiotaped. The students have not taken chemical equilibrium before. Therefore, I was able to investigate the effectiveness of the learning processes.

Research design The study is used a straightforward design with a pre- and posttest. In order to collect necessary information, the study has ways of obtaining data as shown in Table 1.

Table 1. Research design of the study

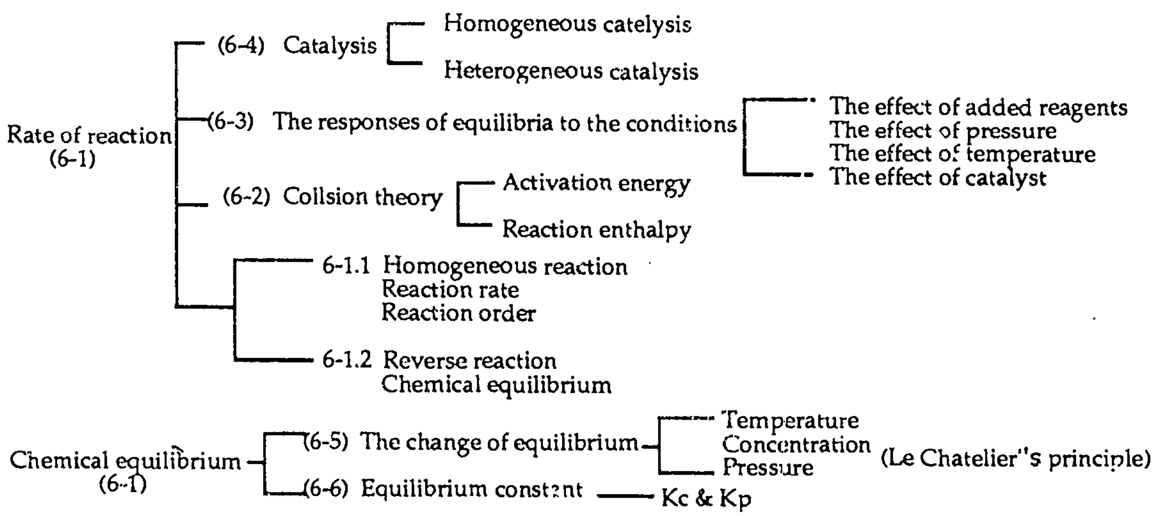
Goals	Treatments	Methods of Data Collection	Tools
Making students familiar with verbal reports techniques	Introduction and demo how to proceed	Audiotaping and translating verbatim	Instruction sheets and example sample
Understanding students' prior knowledge	Conducting a pretest	Audiotaping verbal reports, timing, and a paper-and-pencil test	Paper and pencil, timer, notes
Investigating students' learning processes	Assigning reading materials	Audiotaping verbal reports, timing, and notes by students	Marker, OHP pens, Paper and pencil, timer, notes
Examining problem-solving processes	Studying examples and problem solving	Audiotaping verbal reports, timing, and a paper-and-pencil test	Paper and pencil, timer, notes
Diagonizing students' performance	Completing a posttest	Audiotaping verbal reports, timing, and a paper-and-pencil test	Paper and pencil, timer, notes

The procedure. Four phases of the study were conducted:

1. An initial interview session (a pre-test) in which each student reported what they knew about 20 terms about the chemical equilibrium, (e.g., reaction rate, equilibrium constant, rates of reaction, free energy, etc., as Type I questions), eight daily experience problems relating to the chemical equilibrium (as Type II questions), and thirteen content-specific multiple-choice and open-ended questions (as Type III questions) (see Appendix I). Their discussion focused on the explanations of each answer. This interview was audiotaped.

2. The students were provided with a 32-pages booklet (the content was taken from a chapter of a national chemistry textbook, See Figure 1), each page of which contained a major concept. The students were told to provide their explanations of understanding the page. This part was designed to investigate how the learning was occurred. A number of specific prompts were inserted at 33 locations throughout the booklet. These locations corresponded to places in the text at which a concept about chemical equilibrium was just discussed, such as reaction rate. Therefore, I was able to evaluate how well they learned during study and then contrast this result with their performance on the posttest. Students were told that they may also take notes and draw diagrams while reading, although they were not prompted to do so.

Figure 1. The content analysis of the reading materials



3. Students were also asked to study three worked-out examples in the booklet, and then they were requested to solve a set of problems. This set consisted of five "chapter" problems, which were problems taken directly from the end of the target chapter and three problems selected from a reference book (after consulting a high school chemistry teacher) to correspond with the content of worked-out examples in the previous step. Each problem had a maximum score of ten points, with partial credit available depending on the answer. This problem-solving task was designed to investigate how students learn from worked-out examples and how students apply their understanding of the concepts and principles to relevant problems.

4. A post-test, an alternative version of the pre-test, was conducted individually. This interview was also audiotaped.

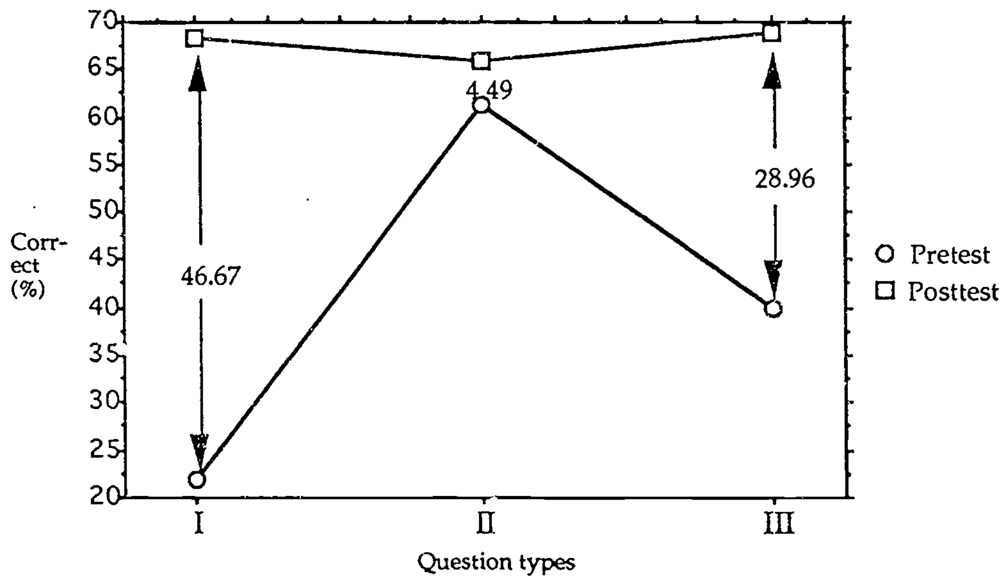
The whole treatment and evaluation lasted for 3-5 sessions with each session spaced a week apart. Each session lasted from 1-3 hours. All sessions were audiotaped and then transcribed for data analysis.

Results

Based on the analysis of pre-test and post-test interviews, probing questions, and self-explanations for reading materials, it is evident that not only were less successful students unable to generate coherent information for understanding the content, but they also cannot successfully apply chemical principles to solve problems both in daily experiences context and content-specific conditions. In the following discussions, I will first describe students' performance on the pre- and posttest, then examine their learning with the examples and investigate their processes of understanding of chemical equilibrium, and finally pinpoint the lack of connections between their knowledge of chemical reactions and problem solving skills based upon their inferences generated during reading. Students were characterized into three groups: successful, intermediate unsuccessful students, based on their overall performance on the tasks discussed earlier.

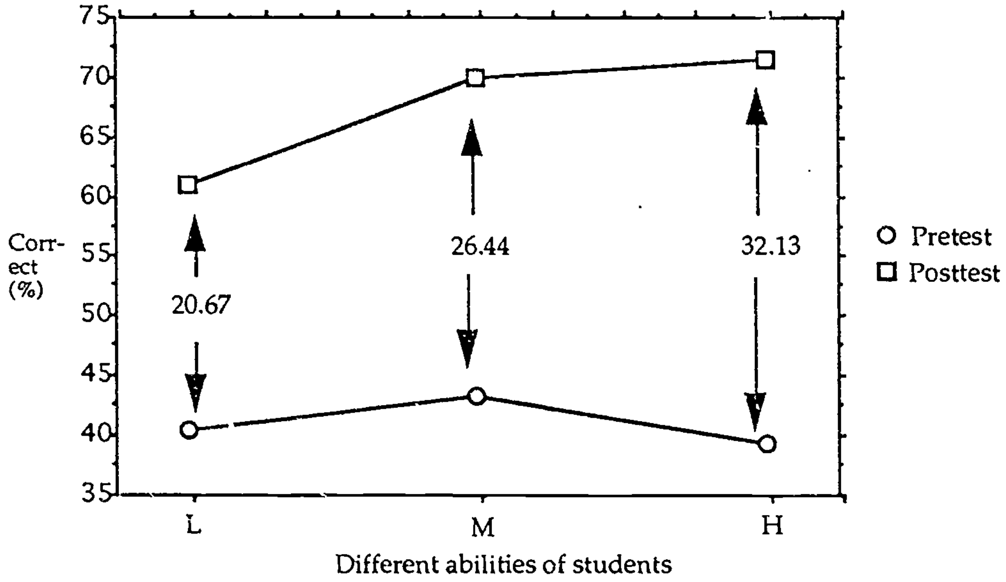
Performance on the pre- and posttest Three types of the questions were conducted to examine how students performed on the tests. The students' performance on each type of the pretest were 21.79 (s.d.=6.32), 61.3 (s.d.=14.64), and 39.87 (s.d.=8.57). The scores on the posttest were 68.46 (14.16), 65.79 (12.84), 68.83 (10.44). Figure 2 indicates that the students have highest gain scores on Type I (46.67), terms related to chemical equilibrium. The lowest gain scores were Type II (4.49) which was relative high on the pretest (See Figure 2).

Figure 2. Students' performance on the pre- and post-test.



Different abilities of students The students were characterized into successful (H), intermediate (M), and unsuccessful (L) groups based on their performance on the prompt questions, problem-solving, and gain scores on the tests. On average, the successful students, the intermediate students, and unsuccessful students were scored 39.95 (12.38), 43.49 (4.71), and 40.4 (6.59) respectively on the pretest. There was no statistically significant difference. In the posttest, each level of the students were scored 71.48 (8.14), 69.94 (5.76), and 61.67 (5.93) respectively. Figure 3 reveals that the gain scores of successful, intermediate, unsuccessful students are 20.67 (4.94), 26.44 (2.11), 32.13 (5.94) respectively. On average, the successful students gained the most as opposed to the unsuccessful students who gained the least. The results indicated that only gain scores between successful and unsuccessful students were significantly different (F=9.2, p=0.05).

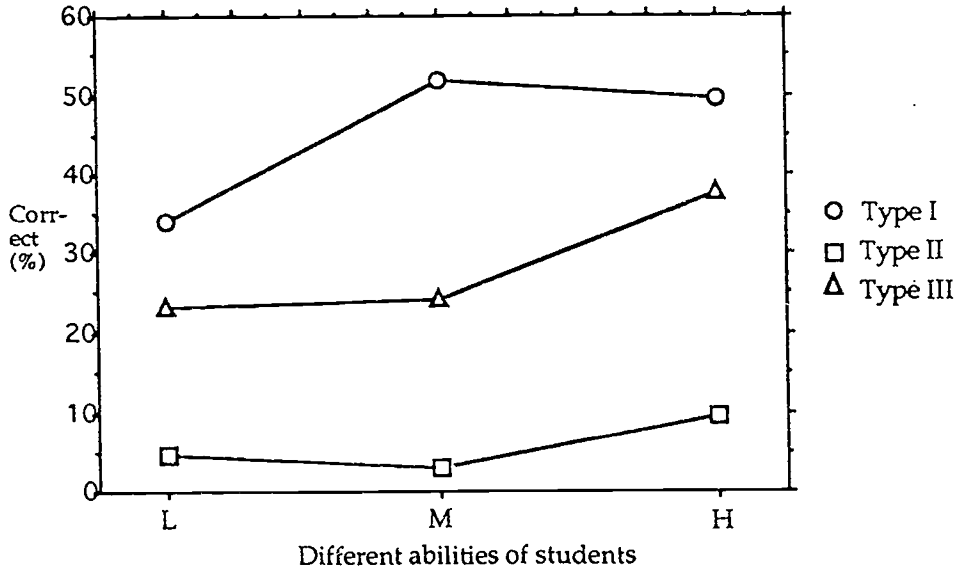
Figure 3. Gain scores on the pre- and posttests by different abilities students



In Figure 4, it further shows that there was no significant difference among three groups on Type II questions. That is, the students did not gain that much on their achievements on daily experiences problems. The gain scores of successful, intermediate, and unsuccessful students are 9.36 (s.d.=11.13), 3.04 (8.83), and 4.55 (17.6) respectively. As for Type I questions, both successful (49.38, sd=8.7) and intermediate (51.88, sd=10.68) students outperformed unsuccessful students (34.17, sd=6.35). They both reached .05 significant level. However, there was no significant difference between successful and intermediate students on Type I questions. As for Type III questions, only those successful students (37.65, sd=11.07) outperformed unsuccessful students (23.29, sd=3.18). The differences were at .05 significant level (F=14.2, p=.05). There was no significant difference between the intermediate (24.42, sd=6.14) and unsuccessful students on Type III questions.

These results pinpoint two major findings. First, both the successful and intermediate students performed equally well on recalling concepts on Type I questions. Second, the successful students outperformed the intermediate and unsuccessful students on more profound questions (e.g.,Type III) in which better understanding of chemical equilibrium concepts is required in order to apply the knowledge to solve problems.

Figure 4. Gain scores on three types of questions by different abilities students



Learning from examples Three examples in the reading materials were used to examine how students used the examples (See Appendix II, Chiu, 1993). The results are shown in Table 2.

Table 2. Understanding of chemical equilibrium from examples by different abilities students.

Unsuccessful	Intermediate	Successful
1. use mol/l correctly	1. use mol/l correctly	1. use mol/l correctly
2. be able to use Kp but not quite sure its meaning	2. be able to use Kp but not quite sure its meaning	2. be able to use Kp and infer its meaning
3. know the relation between volume and molarity, but	3. know the relation between volume and molarity, but	3. know the relation between volume and molarity and be

cannot apply	cannot apply	able to apply it correctly
4. unable to capture the meaning of each step in the examples	4. unable to capture the meaning of each step in the examples	4. able to capture the meaning of each step in the examples
5. unable to calculate the solution concentration in equilibrium state	5. mistake total amount of reactants to be used up for yielding products	5. know the relations of solution concentrations among the reactants and products
6. unsure about the exponents of equilibrium constant	6. know the meaning of the exponents of equilibrium constant and able to apply	6. know the meaning of the exponents of equilibrium constant and able to apply
7. name a compound by its formula	7. name chemical compounds by formulas or by IUPAC	7. name compounds correctly

According to the results above, there are four major findings. First, all the students understood the relationships between volume and concentration. However, only the successful students were able to use that reverse relations to explain the change of concentration of the mixtures in the reaction system. In particular, the more successful students were able to depict the condition for reversed relations when the amount of solutes is constant. Second, due to limited information presented in the examples, the students have to infer what each step stands for. Besides, the successful students were able to apply their knowledge of chemical equilibrium and relevant information appropriately for understanding examples. However, the unsuccessful students were lack skills and knowledge of understanding the examples both for explicit and implicit information. This was quite difficult for unsuccessful students. Third, even thought the text has explicitly stated the meaning and associations of powers of each compound, the unsuccessful students were unable to use it appropriately in understanding the problem solving procedures. Finally, the more successful students tend to use appropriate chemical names for compounds, whereas the unsuccessful and intermediate students were more towards to call them by formulas.

Problem solving in exercises Table 3 reveals that the successful students were able to use integrative knowledge of chemical equilibrium to solve problems, whereas the unsuccessful students were confused about some relations of equilibrium concepts and then used them inappropriately. Also, the successful students were able to use knowledge from another domains (i.e., mathematics) on their current task, whereas the unsuccessful students lacked chemical-mathematical skills for success. For instance, although all the students were unable to make proper simplification by approximations, the successful students were able to solve a quadratic equation for x and even to judge which of these two solutions is physically meaningful. While the unsuccessful students tended to reply "I don't know how to solve this quadratic equation." or "It's too complicated." Extensive analysis of thinking-aloud protocols revealed that the successful students showed a high motivation to complete the task even when they had impasses, whereas the unsuccessful students tended to give up their work when difficulties arose. In addition, the unsuccessful and intermediate students lacked abilities to differentiate Kc, k (reaction rate), and the effect of original concentrations of reactants. Lack the ability to use knowledge and skills appropriately nor differentiate the conditions to apply them correctly has been discussed in many studies. It is shown again in this study that the unsuccessful students were unable to apply mathematical skills in problem-solving in chemistry.

Table 3. Problem solving performance by different abilities students

Unsuccessful	Intermediate	Successful
1. K=Kr when T=constant	1. K=Kr when T=constant	1. K=Kr
2. Volume increases, molarity decreases. Not sure how Kc changes.	2. Volume increases, molarity decreases. Not sure how Kc changes.	2. Know concentration changes, Kc does not change (when T is constant)
3. easy to make slips	3. able to calculate the Kc but unable to detect the error	3. able to use concentration, mathematical ways to get Kc
4. always to assume the reactants used up or used half of the original amount.	4. always to assume the reactants used up. If it does not fit, try another way.	4. able to use appropriate concentrations and conditions to solve problems.
5. not able to use scientific symbols	5. try to use scientific symbols but not sure if it correct	5. able to use scientific symbols

The results indicate that the students learned better on the questions taken from the end of the chapter. However, the students learned less on those questions taken from outside the text but related to the content. It suggests that the students show some difficulties in successfully using the principle involved in the example in a different and more complex problem, because such problems prevent students from being able to solve them via a syntactic mapping. As Swell and Cooper's research (1985) indicates, students who have studied examples often cannot solve problems that require a very slight deviation from those studied (eg., example solution).

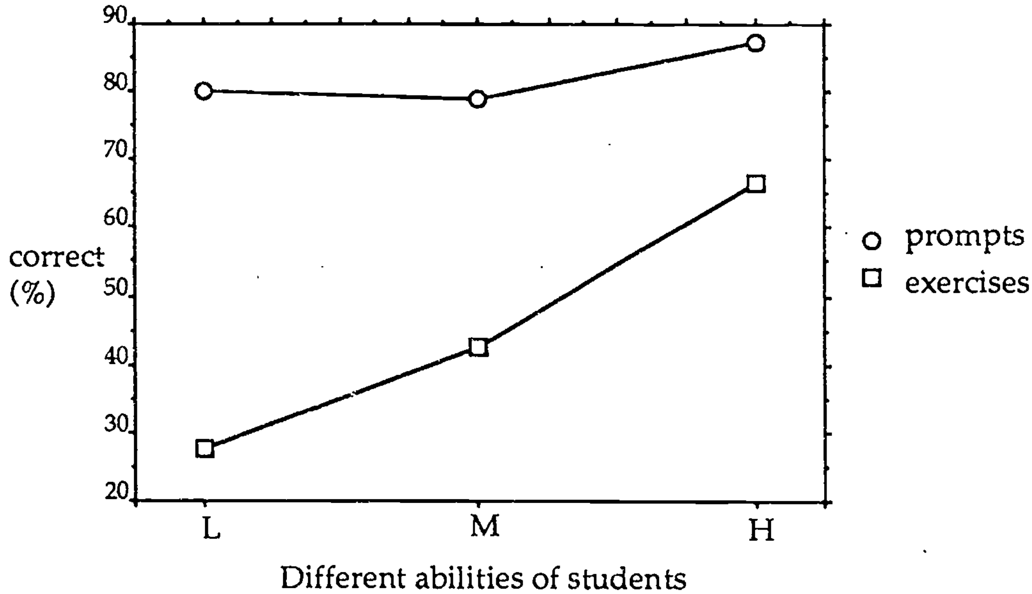
Also, the successful students were able to learn more from their experience of solving the problems. That is, the successful students were able to relate the previous questions to the current questions. The results also reveal that they used the previous strategies for solving a current task. This back and forth reference was found frequently, in particular, for those questions next to each other. This finding is consistent with Nisbett and Ross (1980)'s research in which they call it as vividness criterion (Table 4).

Table 4. The frequencies of using the examples and the text during problem solving by different abilities students

	Unsuccessful	Intermediate	Successful
referring to the examples	11	6	11
learning by doing (referring to previous problems)	1	2	4
referring to the text (looking for reaction formulas)	4	1	0

Prompts and problem solving Prompts performance was mainly to examine their understanding of declarative knowledge. Their scores are 87.15 (sd=3.51) for successful students, 78.84 (sd=5.59) for intermediate students, and 79.89 (sd=9.21) for unsuccessful students. There was no significant differences of percentages of correct prompt answers among three different abilities students. However, the students were significantly differentiated on their problem solving task (F=18.58, p= .05, See Figure 5). Their scores are 66.48 (sd=14.89) for successful students, 42.64 (sd=2.41) for intermediate students, and 27.84 (sd=9.21) for unsuccessful students. It indicates that the students did not perform differently on memory task, however, they acted differently when it is required to transform their declarative knowledge (i.e., Le Chatelier's principle) to procedural knowledge for problem solving.

Figure 5. Performance on prompt question and exercises by different abilities students



Inferences generated during studying In order to understand the materials presented explicitly in the text, the learners should be able to make different degrees of inferences during studying. Although the learners can generate varieties of inferences, I only examine those inferences which sound more plausible and logical inferences, and then assign its category based on its function (van den Broek, Fletcher, & Risden, 1993). Therefore, inferences generated from studying the materials by the students were investigated in order to uncover the impasses of learning the concepts of chemical equilibrium. The major categories of inferences were adapted from Chi, de Leeuw, Chiu, LaVancher (1991)'s study. There are six kinds of inferences found in this study:

1. Reference inferences: including paraphrases.

Reads All the other gases are colorless, the change of color stands for amount of CO_2 changed within a certain time interval (p.3).

Explains CO is that gas without color.

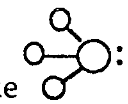
2. Commonsense inferences: the application of commonsense knowledge.

Reads The unit for reaction time always depends upon the speed of a reaction, we can use seconds, minutes, hours, or days, even years...(p.4)

Explains If the reaction is very slow, we then use hours as units. If we use seconds as units, it might be too big...

3. Relevant inferences: the use of background knowledge that is relevant to the subject matter.

Reads Figure 4-8 (see Appendix III) shows the directions of collisions between HCl and NH3... (p.10)

Explains (Figure 4-8 including a compound structure like )... the dots are covalent electrons...

4. Comparative inferences: Comparing the content knowledge back and forth.

Reads After reading homogeneous (p.19) and heterogeneous (p.20) catalysis...

Explains One is dissolved mutually and the other one is not .. for instance the iron cation dissolves in H_2O_2 to form a same phase solution (p.19), whereas the Fe cannot dissolve or make a same phase with H_2 and N_2.. so they are in different phases (p.20)..

5. Logical inferences: the use of deduction from studying materials.

Reads Figure 4-8 (a) shows that it requires the lowest activation energy for the most suitable direction of collision between moleculars. Figures 4-8 (b) & (c) indicate the inappropriate directions of moleculars' collisions, requiring higher activation energy, they are called insufficient collisions.

Explains .. The most appropriate position..the lowest activation energy, making an effective collision.. otherwise it is an ineffective collision.. therefore, we know most of collisions are ineffective.. because the probability of having right direction is quite low...

6. Integrated inferences: Application of information presented in previous sections.

Reads Reversible reactions reach an equilibrium state. The equilibrium mixtures have the following relations [i.e., Kc]... (p.7)

Explains Reversible reaction reaches a dynamic equilibrium, and then their reaction rate is equal (p.2).. Yah, just like what we learned in previous pages about the reaction rate (p.3), the exponential figures for reactant concentration is from the experiment (p.6).. but the powers of reactants in the other formula (e.g., equilibrium constant) come from the parameters of the mixtures in the equilibrium reaction formula.... (p.7)

Mechanism of generating inferences The following discussions use primary concepts as units of analysis to examine the connections of concepts via inferences. Figure 6 indicates that a model of possible mechanism of generating local inferences by the students. Figure 7 indicates that a model of possible mechanism of generating global inferences by the students. The real curve lines are for local inferences within a major concept either referring forward or backward to relevant concepts, whereas the dashed curve lines considered as global inferences between chemical equilibrium concepts. The arrows stands for the sequences of chemical equilibrium concepts in the text. In this study, I found that the successful students tended to elicit both local and global inferences as opposed to unsuccessful students who produced more local inferences during reading the materials. The intermediate students did not have a consistent performance on generating inferences as I found in the successful and unsuccessful students. However, I did find that all the students tend to generate more inferences within each concept as opposed to between different concepts. Further, all the students generated more backward inferences than forward inferences for predicting the following sessions. The average frequencies of backward and forward inferences for all students are 11.67 and 3.67 respectively.

Figure 6. Students' possible mechanism of generating local inferences.

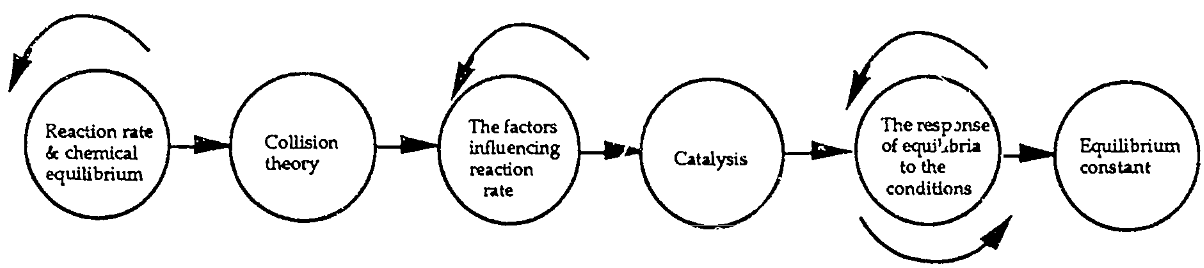
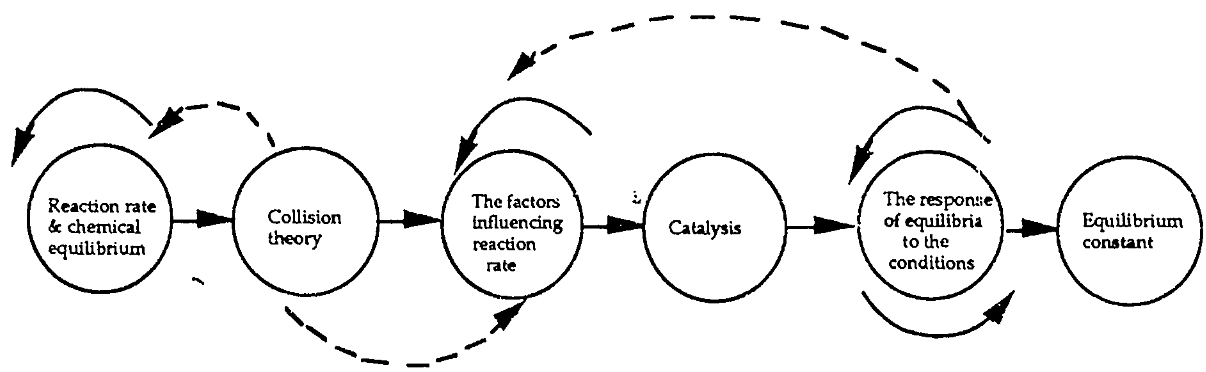


Figure 7. Students' possible mechanism of generating global inferences.



From the analysis and discussions above, I propose a conceptual framework of potential factors that might influence the processes of generating inferences (See Figure 8). This model depicts that a learner's mental representation of content knowledge might be influenced by his/her background knowledge, inferences, and the sequences and contents of the materials. In particular, the inferences occurred (either locally related or globally related) shed some light of learning mechanism by the learner.

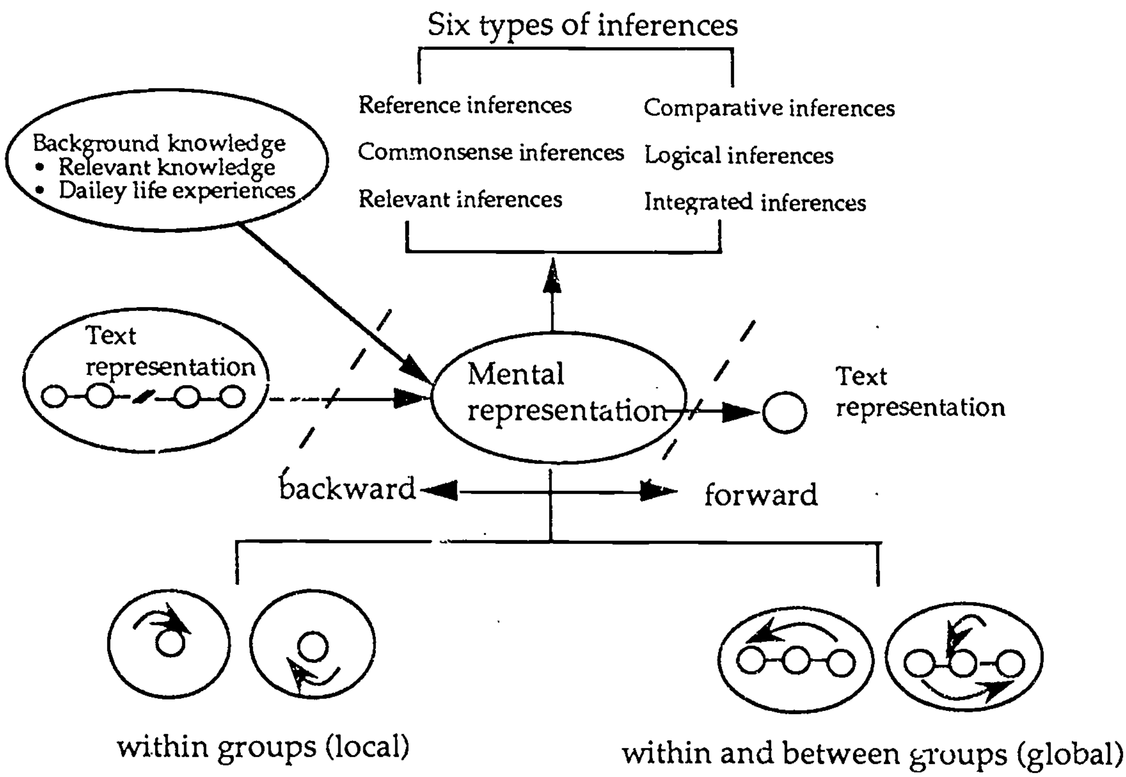


Figure 8 The factors and mechanism of generating inferences by the learner

Discussions and conclusions

Based upon the analyses above and more extensive investigation of protocols, these results reveal both the successful and intermediate students performed equally well on recalling concepts, while only the successful students were able to answer more profound questions in which better understanding of chemical equilibrium concepts is required in order to apply the knowledge to solve problems. The following discussions further suggest some extents of our understanding of students' knowledge and problem solving of chemical equilibrium.

Inability to decide when to use the concepts of moles and molarity. To calculate equilibrium constant, it is required to use molar concentrations of reactants and products in the balanced equation. I found that the unsuccessful students tended to use moles of equilibrium composition of the reaction mixture for calculating Kc, whereas the successful students were able to obtain the correct molar concentrations before substituting of all equilibrium concentrations into the expression for Kc. The intermediate students used various strategies for problem-solving tasks (more expert-like type).

Misuse the constancy of the equilibrium constant Le Chatelier's principle predicts that a chemical equilibrium will respond to an increase in temperature by absorbing heat. Therefore, if there is no temperature change, the value of Kc (or Kp) is constant. Most of the students were able to state correctly the effect of temperature, however, a considerable amount of students misapplied this rule to a reverse reaction. For example, one of the questions asks the students to calculate the value of Kc for the reaction $H_{2(g)} + I_{2(g)} \dashrightarrow 2\ HI_{(g)}$ when the equilibrium concentrations of all the mixtures are known, and then calculate the value of the decomposition reaction at the same temperature. There were 41.66% of the students replied that the value of the Kc for the decomposition reaction is the same value of the Kc for the forward reaction.

Competing equilibria Suppose we added water to an equilibrium system, according to Le Chatelier's principle, the equilibrium would tend to adjust so as to reduce the increase in the concentration of water. Majority of the students were able to state how the effect of added reagents, however, they were unable to adapt their knowledge to a related problem situation. For instance, the question shown below asked the students to calculate $[Fe^{3+}]$ when the original volume of the water was doubled. All the students failed to consider the new condition of the equilibrium changed and then simply just divided original $[Fe^{3+}]$ 0.1M by 2 for the final $[Fe^{3+}]$.

In an equilibrium system, $Fe^{3+}(aq) + SCN^{-}(aq) \longleftrightarrow FeSCN^{2+}(aq)$, $[FeSCN^{2+}] = 0.1M$, $[Fe^{3+}] = 0.1M$, $[SCN^{-}] = 0.2M$. Calculate the equilibrium constant. Suppose we add some water to double the volume of the original solution. What is the final concentration of Fe^{3+}?

Unable to generate the definition of zero order of a reaction The overall order of a reaction is the sum of the powers to which the individual concentrations are raised in its rate law. It is quite interesting to find that all the students were able to provide correct definition of reaction order. However, all the unsuccessful students were unable to make inference of zero order of a reaction which was not explicitly stated in the reading materials. Only the intermediate and successful students were able to make correct inferences about the meaning of zero order of a reaction.

Differences of understanding of worked-out examples. As analyses shown, the students learned from the text and from the examples. The finding suggests that successful students generated their explanations which made their understanding of the concepts and principles more coherent and meaningful, while unsuccessful students' explanations for the content tended to show their inconsistency of understanding. As Zhu and Simon (1987) stated, presenting students with carefully chosen sequences of worked-out examples and problems, without lectures or other direct instruction, students can still show their learning from examples and learning by doing. However, worked-out examples with insufficient information might create some difficulties for low achievers.

Different mechanism of generating inferences. As Gagne (1993, p.275) pinpoints that successful reading comprehension requires inferential comprehension which involves going beyond the idea explicitly stated to integrate, summarize, and elaborate on these ideas. In this study, it shows that the abilities of generating relevant inferences during study heavily influenced students' performance. The successful students were able to use related knowledge to infer the implicit information while the unsuccessful students lacked to " see" the inter-relationships between the concepts, therefore, they were less skillful to gain deep understanding of the content. In Chan et al.'s (1992) study, they propose a constructive activity in learning from text. The highest level of the activity in their model is extrapolation which requires to construct inferences beyond the presenting text. This might also explain why those less successful students in this study were unable to formulate coherent understanding of the concepts.

The findings point to suggestions for learning processes: (1) to lead to better understanding of the content via elaborations, (2) to provide meaningful explanations of the worked-out examples, and (3) to help students integrate their knowledge of the concepts and principles.

Implications

Students were good at memorizing declarative knowledge. Students sometimes state their understanding of certain concepts and principles clearly, but when they were probed to explain more deeply or asked to apply them to word problems, they could hardly use the concepts or principles successfully. It indicates that our students only had pieces of information and could not integrate them to explain. For example, nine students (75%) answered correctly the item, " What is the definition of rate constant?" , but only six students (50%) could calculate it correctly from experimental data.

The degrees of understanding of worked-out examples influence students' problem solving performance. Students often fail to fully understand the procedures of work-out examples in the textbook. In their protocols, they stated that they have difficulties to understand the problem solving procedures which always eliminate some crucial steps for understanding. Some students, particularly, the low performance students, tend to copy solution paths from the examples to the problems. They sometimes feel hopeless when the problem needs more thinking and integration to solve it. For instance, the unsuccessful student showed an incomplete and poor quality of understanding of the examples: he did not inquire how moles of products were yielded in relation to the coefficients in the balanced equation. They need to have more complete explanations to understand problem solving processes. However, the more successful students were able to apply their knowledge of chemical equilibrium from the text to understand the examples.

The quality of self-explanation influences their understanding of the learning materials. From the analysis of students' protocols before, during, and after the treatment, I found that not only the quantity but also the quality of the explanations provided by the students shed the light of their understanding. The successful and intermediate students were more skillful to link the information presented in the textbook to the problems. However, the unsuccessful students treated the information separately and memorized concepts without fully integrated them. Therefore, I conjecture that self-explanations play an important role in meaningful learning, in particular, for more successful students.

Although this study has provided some conclusive results for our understanding of the students' learning in chemical equilibrium, I am also collecting data from a control group which is not requested for the use of self-explanations in order to further investigate the effect of self-explaining strategy. They will be reported in the future in order to further support that nature and content of self-explanations promotes science learning.

References

Anderson, J. R. (1990). *Cognitive Psychology and Its Implications.* Freeman and Company.

Camacho, M. & Good, R. (1989). Problem solving and chemical equilibrium: Successful versus unsuccessful performance. *Journal of Research in Science Teaching*, 26, 3, 251-272.

Chan, C. K. K., Burtis, P. J., Scardamalia, M., & Bereiter, C. (1992). Constructive activity in learning from text. *American Educational Research Journal*, 29, 1, 97-118.

Chi, M.T.H., de Leeuw, N., Chiu, M.H., & Lavancher, C. (1991). The use of self-explanations as a learning tool. Milestone report for Office of Educational Research and Improvement (OERI), US Ministry of Education.

Chi, M.T.H., de Leeuw, N., Chiu, M.H., & Lavancher, C. (1994). Self-explanations elicit conceptual understanding. *Cognitive Science*, 18, 439-477.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems, *Cognitive Science*, 13, 145-182.

Chi, M. T. H., Glaser, R. & Farr, M. J. (1988). *The Nature of Expertise*, Lawrence Erlbaum Associates, Publishers, Hillsdale, New Jersey.

Chiu, M. H. (1993). *Developing problem solving skills in chemical equilibrium.* Paper presented at the Annual Meeting of National Association for Research in

Science Teaching, Atlanta, Georgia, USA. April 15-19. (ED 362 402)

Gabel, D. L., Sherwood, R. D., Enochs, L. (1984). Problem-solving skills of high school chemistry students, *Journal of Research in Science Teaching*, 21(2), 221-233.

Gagne, E. D., Yekovich, C. W., & Yekovich, F. R. (1993). *The cognitive psychology of school learning*. Haper Collins College Publishers: New York.

Gorodetsky, M. & Hoz, R. (1985). Changes in the group cognitive structure of some chemical equilibrium concepts following a university course in general chemistry, *Science Education*, 69(2), 185-199.

Gussarsky, E. & Gorodetsky, M. (1990). On the concept "chemical equilibrium": The associative framework, *Journal of Research in Science Teaching*, 27(3), 197-204.

LeFevre, J., & Dixon, P. (1986). Do written instructions need examples? *Cognition and Instruction*, 3, 1-30.

Sweller, J. & Cooper, G. A. (1985). The use of worked examples as a substitute for problem solving in algebra. *Cognition and Instruction*, 2, 59-89.

van den Broek, P., Fletcher, C. R., & Risden, K. (1993). Investigations of inferential processes in reading: A theoretical and methodological integration. In A. C. Graesser (Ed.). *Discourse Processes*, 16, 169-180. Ablex Publishing Corporation.

Zhu, X. & Simon, H. A. (1987). Learning mathematics from examples and by doing. *Cognition & Instruction*, 4(3), 137-166.

Appendix I

Sample items

Type I: Describe the following items.

1. catalyst
2. reaction rate
3. equilibrium constant
4. reaction rate
5. free energy

Type II: Use concepts of chemical equilibrium to explain the following phenomenon.

1. Why does a fan make you feel cool in summer?
2. Why does water splash out when a person skates thru ice surface ? And then why does the ice surface become merged again ?

Type III:

1. Given the following chemical reactions and new conditions, decide which one will increase concentrations of a compound underlined.

(1) $CaCO_{3(s)} \rightarrow CaO_{(g)} + \underline{CO_{2(g)}}$ (add little amount of CO_2)

(2) $CH_3COOH_{(aq)} + H_2O \rightarrow CH_3COO^{-}{}_{(aq)} + \underline{H_3O^{+}{}_{(aq)}}$ (add water)

(3) $PCl_{5(g)} \rightarrow PCl_{3(g)} + \underline{Cl_{2\,(g)}}$ (add Cl_2)

(4) $N_2O_{4(g)} \rightarrow \underline{2NO_{2(g)}}$ (reduce volume)

(5) $NH_4Cl(s) \rightarrow \underline{NH_{3(g)}} + HCl_{(g)}$ (reduce volume)

2. For $N_2(g) + 3\,H_2(g) \rightarrow 2\,NH_3\,(g)$ H = - 22Kcal
   5 liters of N_2 and 5 liters of H_2 are in a 10 liter container. Please answer the following questions.

   (a) Please describe whether the equilibrium will be shifted and explain why.
   (1) Add $N_2(g)$
   (2) Add $NH_3(g)$
   (3) Increase pressure
   (4) Increase temperature
   (5) Decrease volume
   (6) Add Fe powder (as catalyst)

   (b) How does the 6 factors in (a) influence the equilibrium constant?

   (c) How does the 6 factors in (a) influence the reaction rate?

   (d) How to increase the yield of NH_3 ?

Appendix II

Example 1: 6 moles of nitrogen and 16 moles of hydrogen were confined inside a 2 liter container, and allowed to reach equilibrium at 638 K. At equilibrium the sample contained 8 moles of NH_3. Calculate the equilibrium constant for the reaction at the temperature of the experiment.

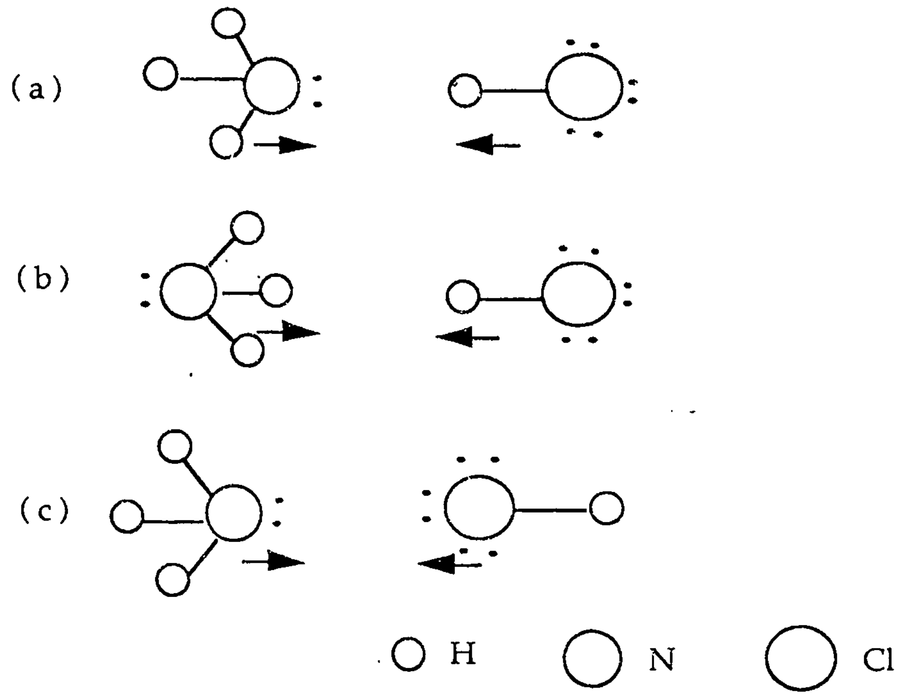
Solution:		$N_2\,(g)$ +	$3\,H_2(g)$	$2\,NH_3\,(g)$
Step 1:	Initial moles	6.00	16.00	0

Step 2:	Moles reducted	-4.00	-12.00	+8.00
Step 3:	Moles at equilibrium	2.00	4.00	8.00
Step 4:	Concentration at equilibrium	1.00	2.00	4.00

$$Kc = \frac{[NH_3]^2}{[N_2]\,[H_2]^3} = \frac{(4.00)^2}{(1.00)(2.00)^3} = 2.00$$

Appendix III

$NH_{3(g)} + HCl_{(g)} \longrightarrow NH_4Cl_{(g)}$



(a) Effective collision (b) & (c) Ineffective collisions

Figure 4-8 Directions of collisions between ammonia and chloride hydrogen